Preparation for a Beam Ion Confinement Experiment on NSTX-U

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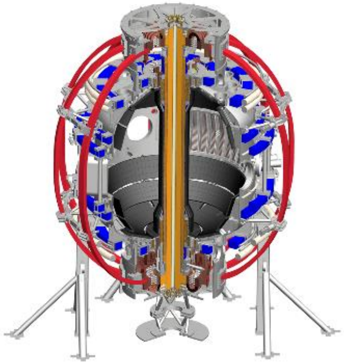
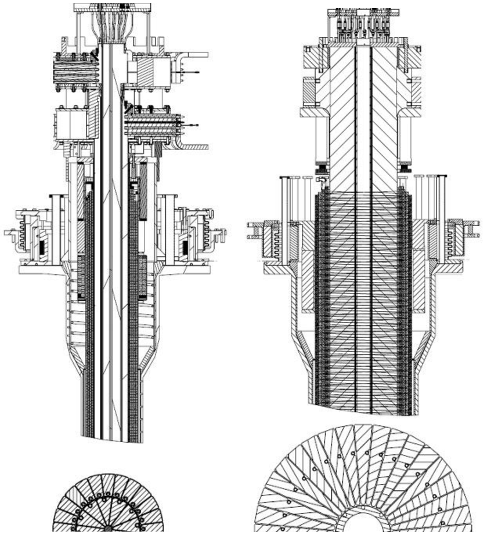


The National Spherical Torus Experiment Upgrade (NSTX-U) will Enable New Fast Ion Physics Study

Previous center-stack

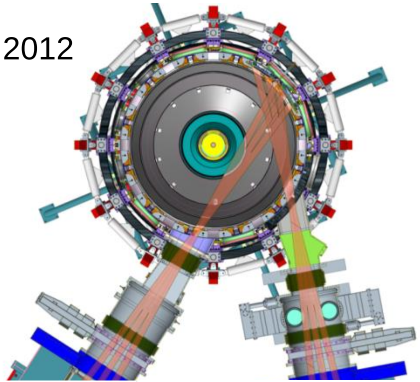
New center-stack



TF OD =20cm

TF OD = 40cm

J. Menard Nucl. Fusion 2012



Present NBI

New 2^{nd} NBI

- New center column will double toroidal magnetic field and plasma current
  - Prompt loss of existing NBI is expected to decrease because of smaller gyro-radius and higher current
- Second neutral beam injection (NBI) system will double heating power and increases flexibility and neutral beam driven current efficiency
  - Fast ion profile can be varied from peaked profile to relatively broad profile, thus changing fast ion driven instabilities
  - Good fast-ion confinement is essential to achieve the anticipated improvements in performance
- A "sanity check" experiment is planned to characterize the fast ion confinement and fast ion distribution produced by the new and existing NBI.

A Comprehensive Set of Fast Ion Diagnostics on NSTX-U

- Neutron detectors

  dominated by beam-plasma reactions, volume integrated

- Fast-Ion D-alpha (FIDA) spectrometers

  sensitive to a swath in velocity space, spatial profile

- Solid State Neutral Particle Analyzer (SSNPA) array

  very localized in pitch angle range, spatial profile, fast time resolution

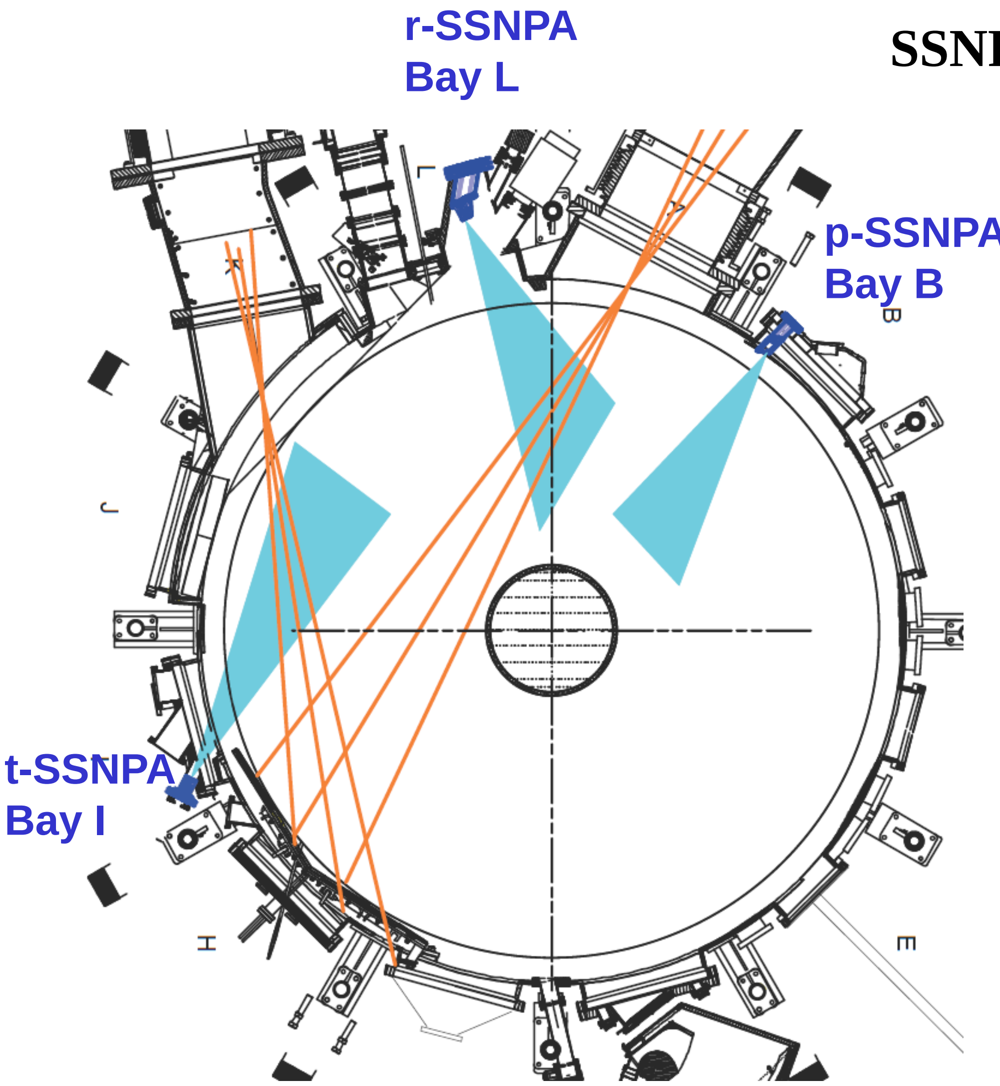
- Scintillator-based Fast Loss Ion Probe (sFLIP)

  lost fast ions, narrow in pitch angle

- Fusion product profile array

  strongly weighted toward high energy fast ions

New SSNPA System Views a Large Range of Plasma & Distinguishes Response from Passing & Trapped Fast Ions



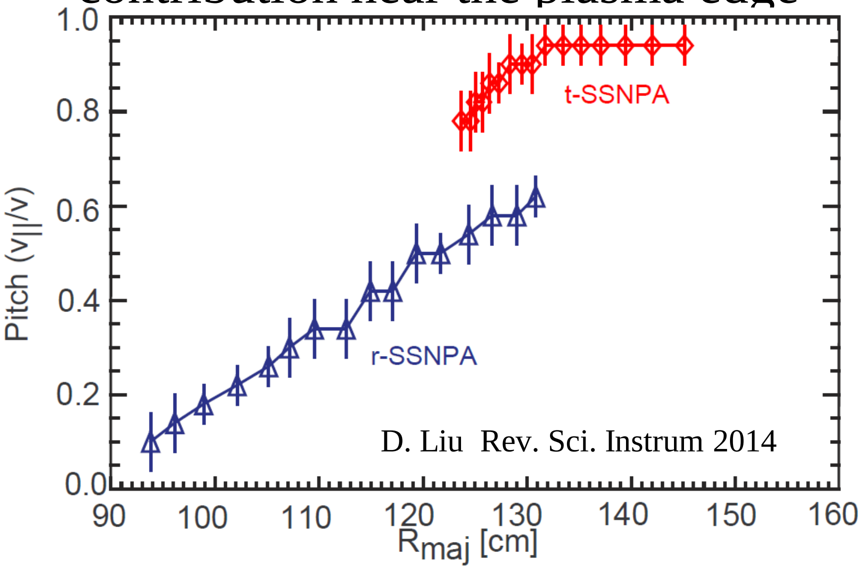
SSNPA measures charge exchange fast ions

- **t-SSNPA at Bay I**

  16 tangential views; passing fast ions
- **r-SSNPA at Bay L**

  16 radial views; trapped fast ions
- **p-SSNPA at Bay B**

  16 reference views; monitor passive contribution near the plasma edge



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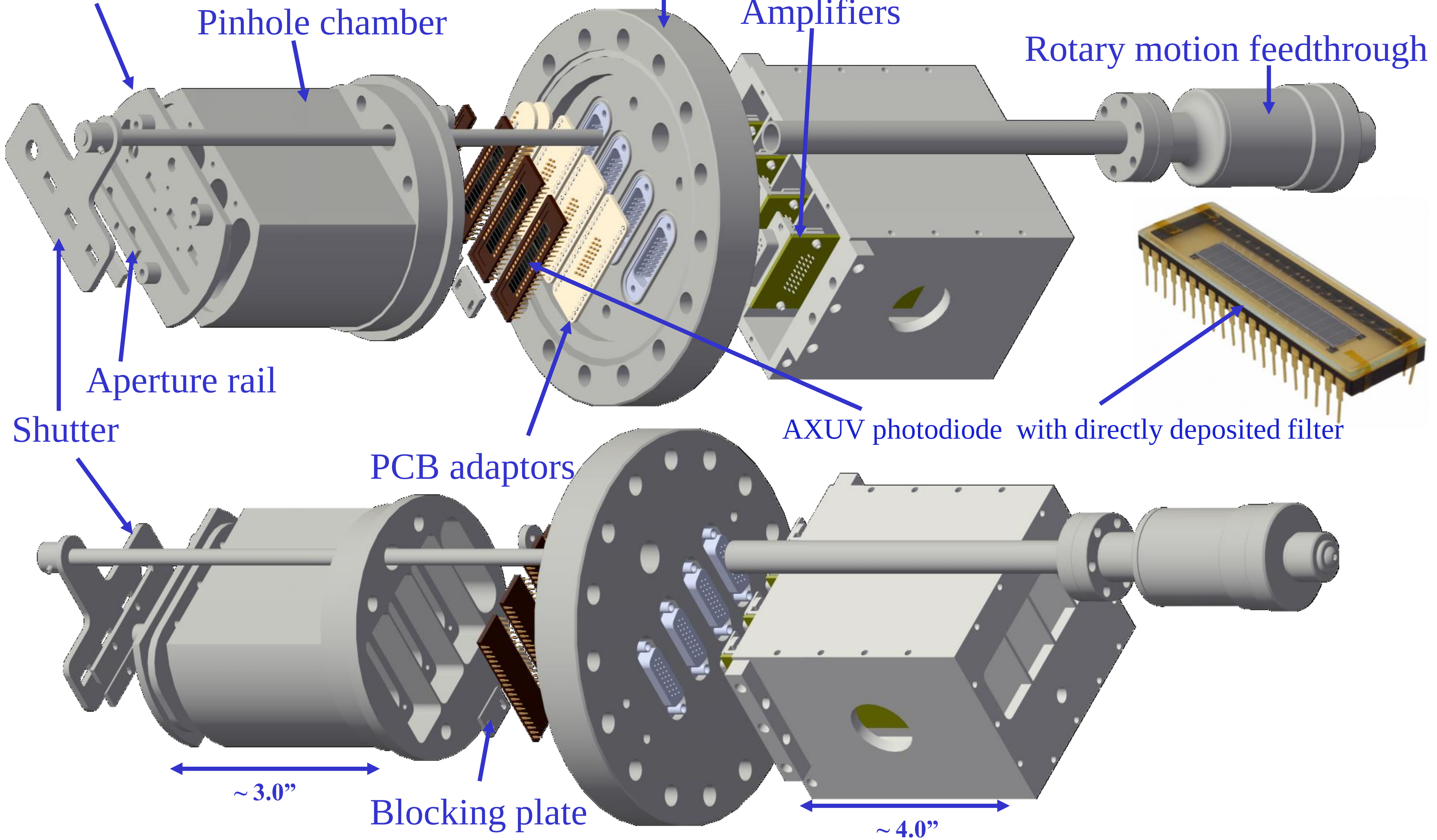
Design Criteria of SSNPA System

- ➢ Reentrant at Bay L and Bay B for desired field of view
- ➢ Stacked arrays with different foil thickness for coarse energy resolution
- ➢ Noise minimization
- ▪ Amplifier is very close to detectors.
- ▪ “Blind” detector monitors EM noise.
- ▪ Low pass filter suppresses high frequency noise.
- ➢ Shutter protects detectors during glow discharges and lithium dropping experiments.
- ➢ Active cooling to protect detectors during bake out.

One Example: Expanded View of t-SSNPA Subsystem at Bay I



Front cover with slits

6” flange with electrical feedthroughs

Pinhole chamber

Amplifiers

Rotary motion feedthrough

Aperture rail

Shutter

AXUV photodiode with directly deposited filter

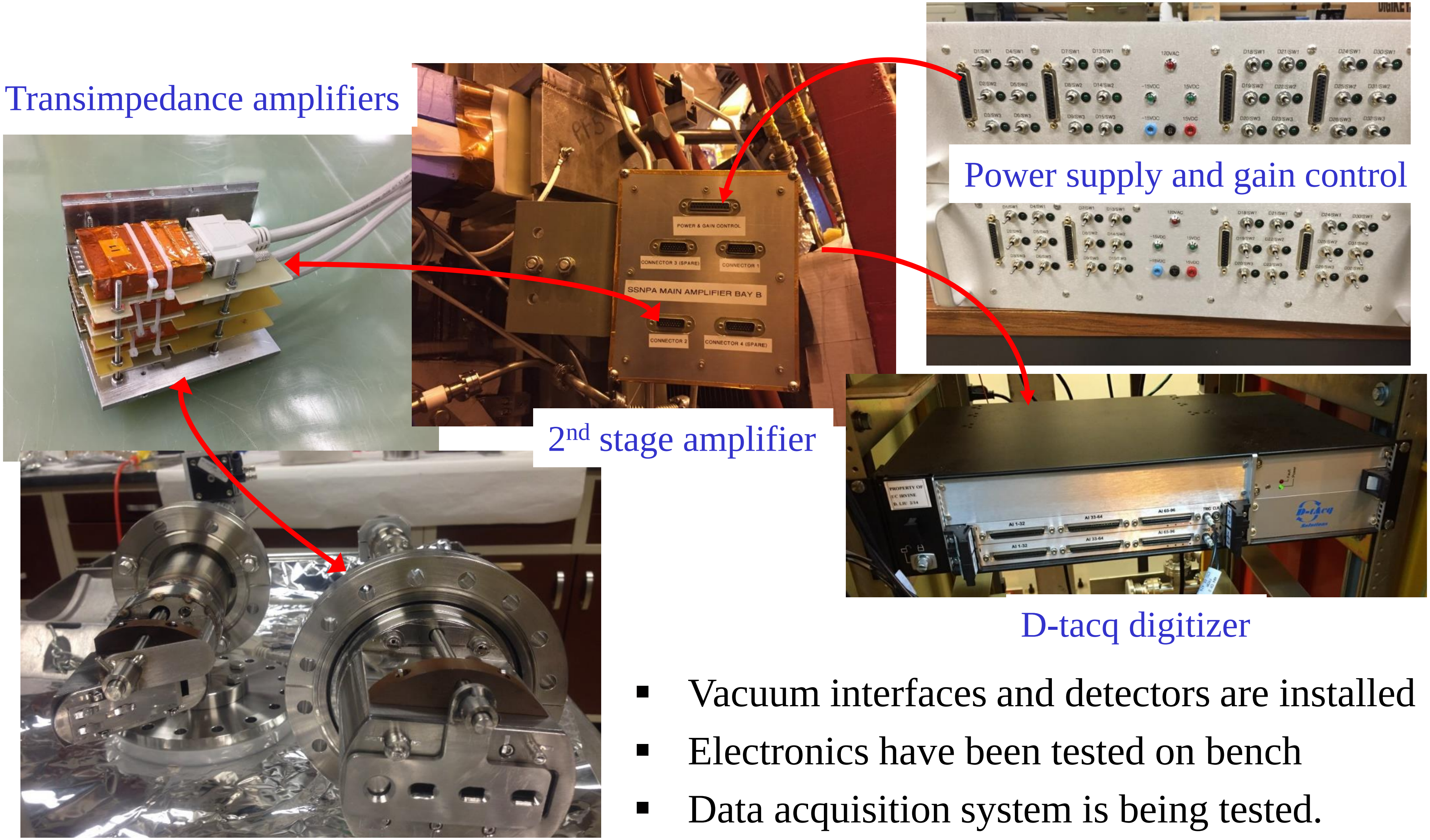
PCB adaptors

Blocking plate

~ 3.0”

~ 4.0”

New SSNPA System is Ready for Plasma Operation



Transimpedance amplifiers

Power supply and gain control

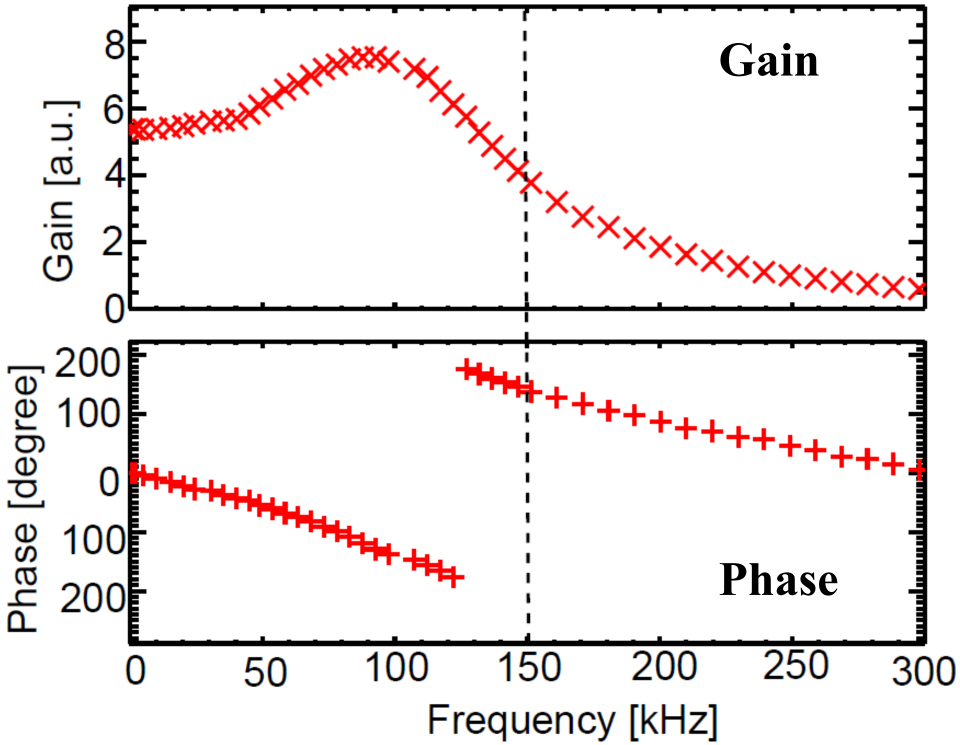
2nd stage amplifier

D-tacq digitizer

Vacuum interfaces with detectors installed

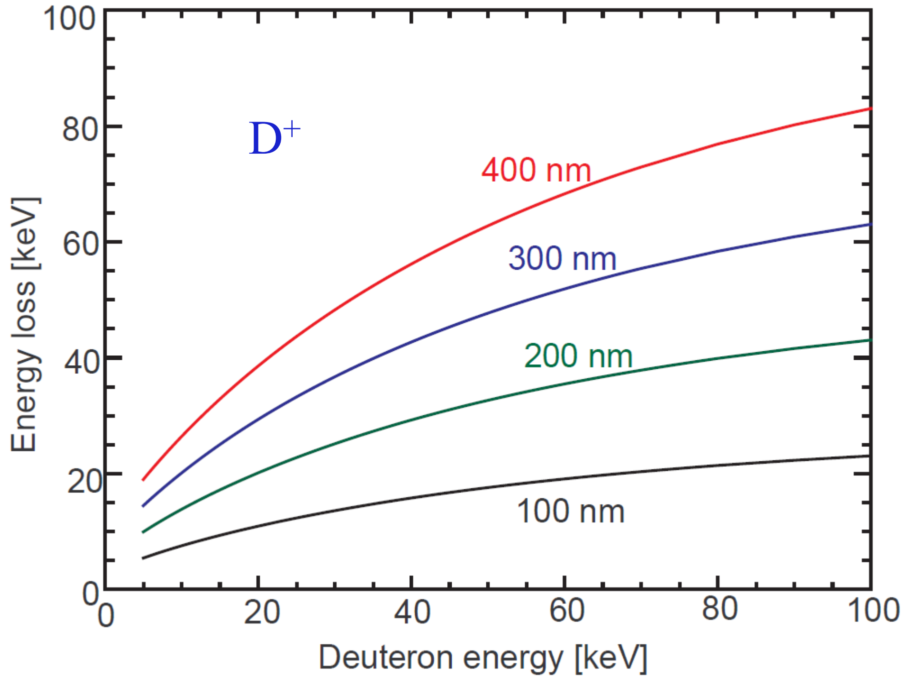
- Vacuum interfaces and detectors are installed
- Electronics have been tested on bench
- Data acquisition system is being tested.

New SSNPA System Aims at Measuring Fast Ion Density Fluctuation up to 150 kHz

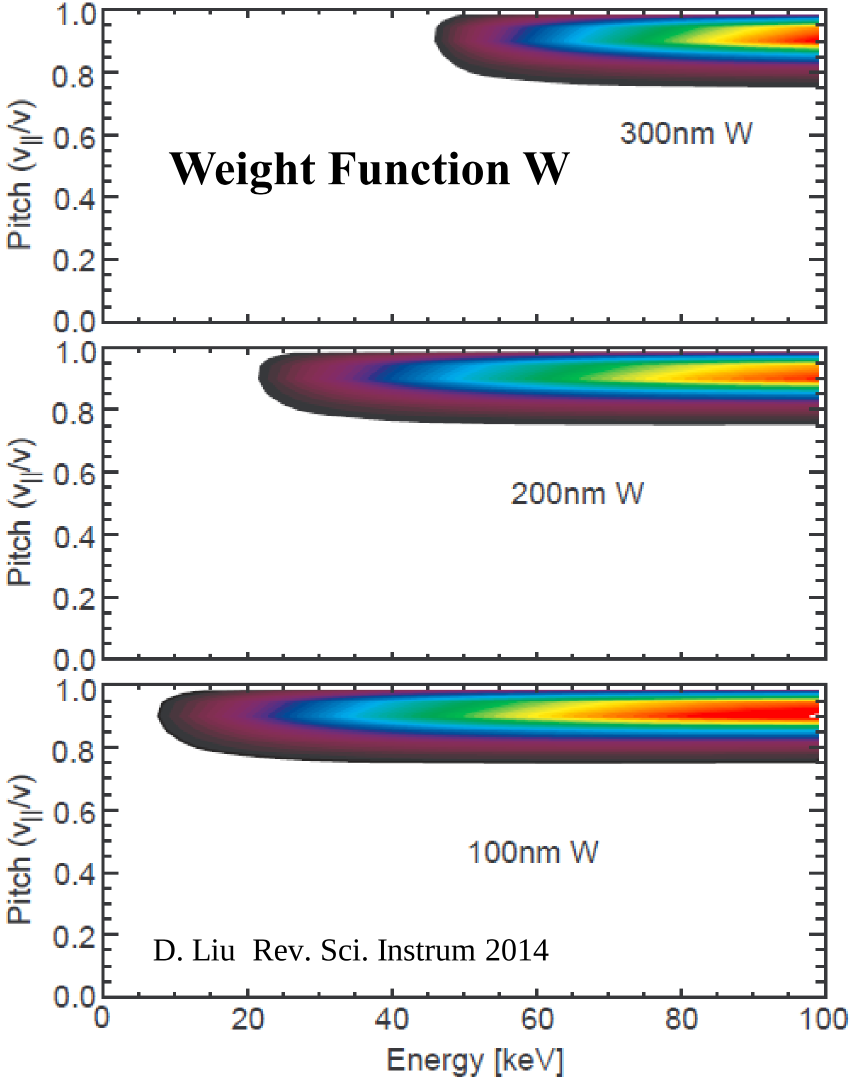


- Bandwidth of amplifier is ~150kHz at gain of $5x10^5$V/A
- Low-pass filters suppress high frequency noise.
- Low noise (<5mV) during on-bench tests.

New SSNPA System will also Obtain Coarse Energy Information



$$S = \iint W F_f \, dE dP$$ F$_f$: **fast ion distribution function**



Weight Function W

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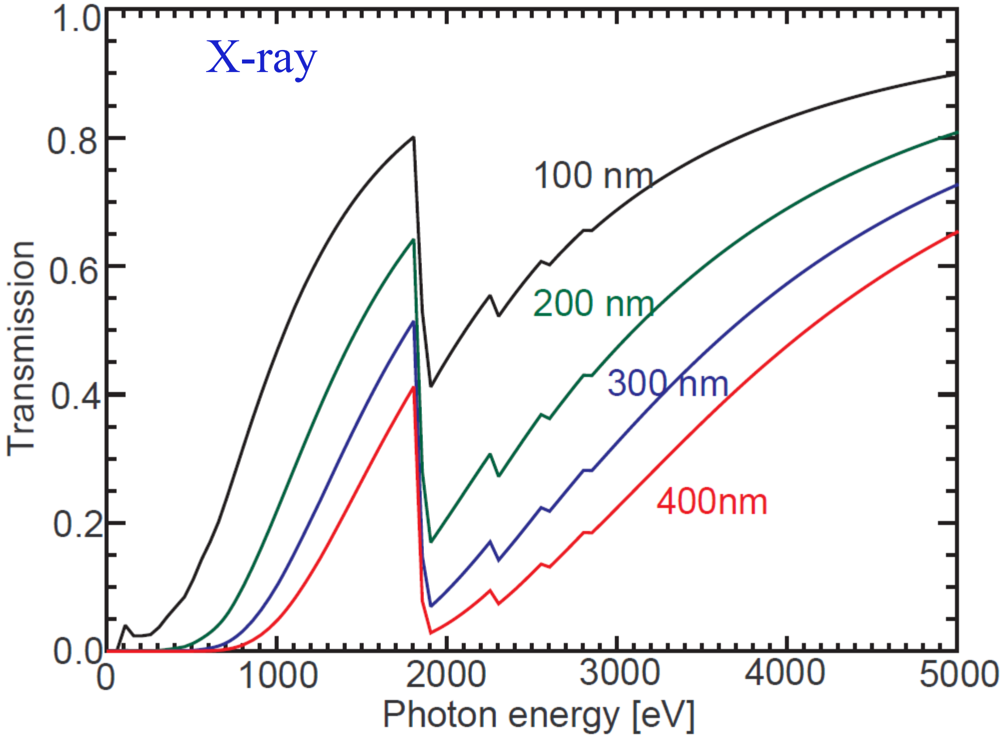
- Thickness of directly deposited filter sets cut-off energy

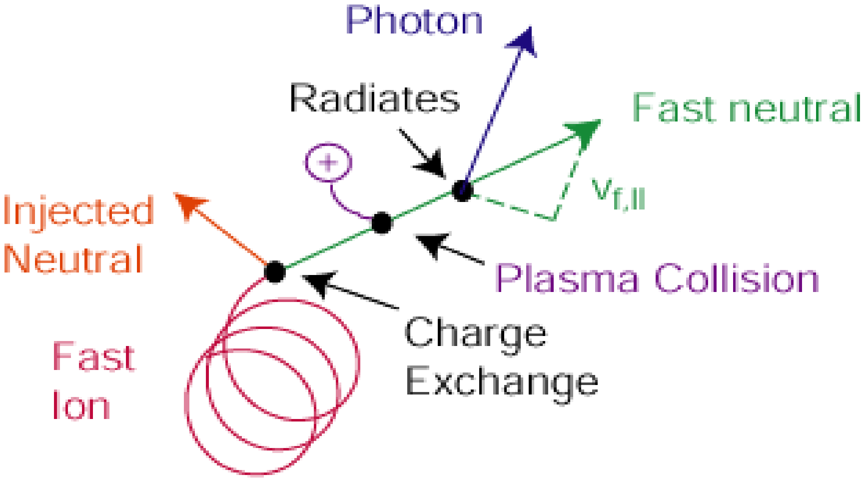
Foil thickness	**Energy loss for 100 keV D$^+$**
100nm	~25keV
200nm	~45keV
300nm	~65keV

Directly Deposited Filters Block Stray Photons



- ➢ Directly deposited filters are more robust and reliable than free-standing foils
- ➢ High Z filter is directly deposited on detectors to block visible light and soft x-ray

FIDA is an Application of Charge Exchange Recombination Spectroscopy

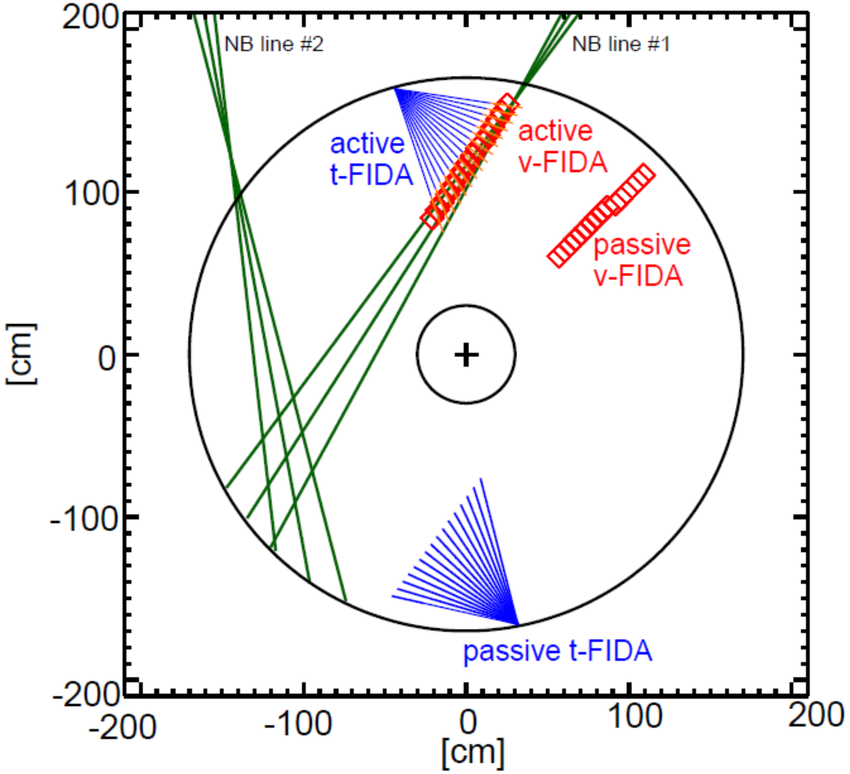


W. W. Heidbrink, Rev. Sci. Instrum. **81** (2010) 10D727

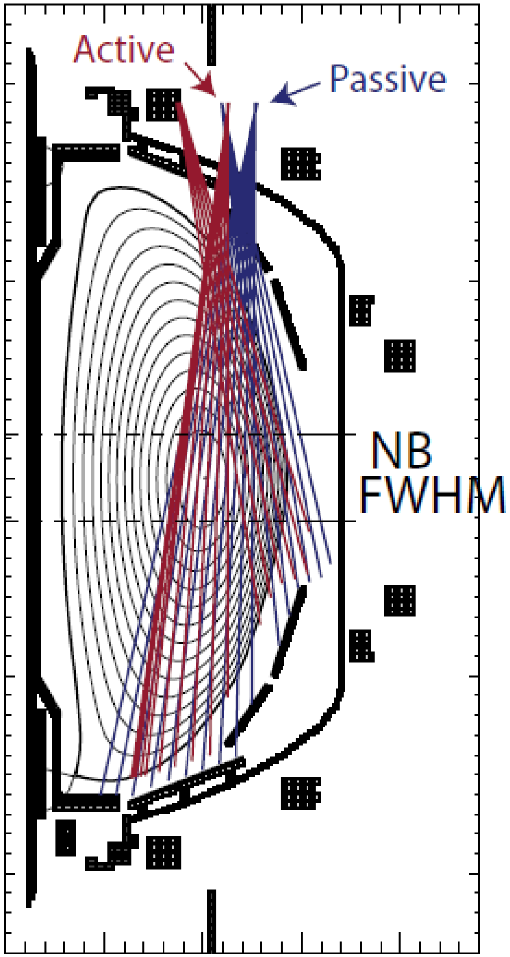
- The fast ion exchanges an electron with an injected neutral
- Neutrals in the n=3 state relax to an equilibrium population; some radiate
- The Doppler shift of the emitted photon depends on a component of the fast-ion velocity

Two Sets of FIDA Diagnostics on NSTX-U

Plan view



Elevation of v-FIDA



V-FIDA: M. Podesta, Rev. Sci. Instrum 2008
T-FIDA: A. Bortolon, Rev. Sci. Instrum 2010

- **Vertical and tangential FIDA Diagnostics consist of two sub-systems**

  - spectrometer-FIDA, full D_α spectrum , 16 channels

    R=0.86-1.66m, 100Hz

  - band-pass filter-FIDA, 3 channels at R=1.0, 1.2, 1.4m, 50kHz

v-FIDA and T-FIDA Systems Separate the Response of Trapped and Passing Fast Ions

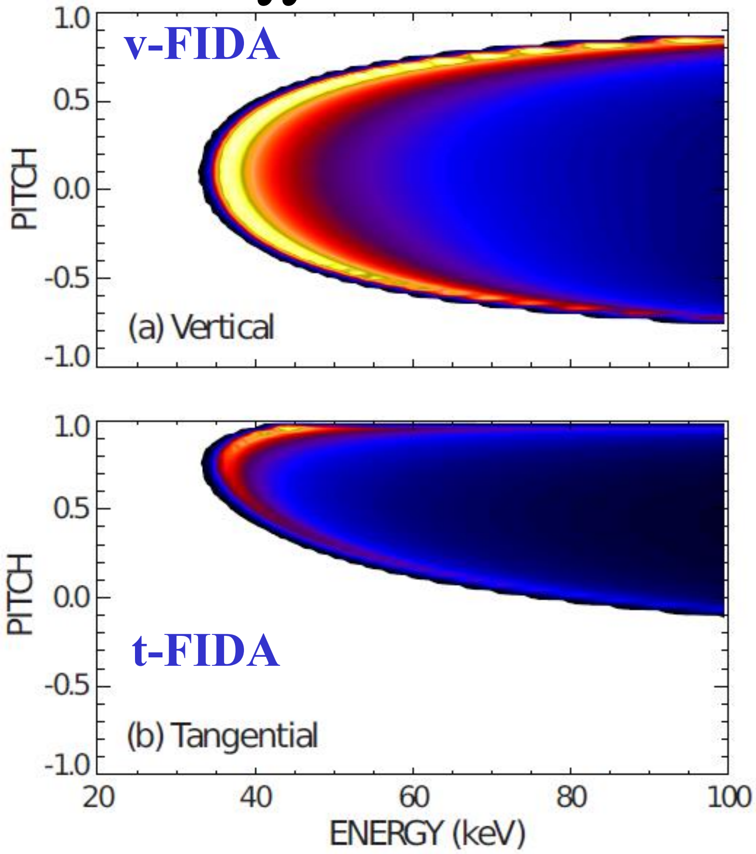
Vertical FIDA

- most sensitive to trapped particles

Tangential FIDA

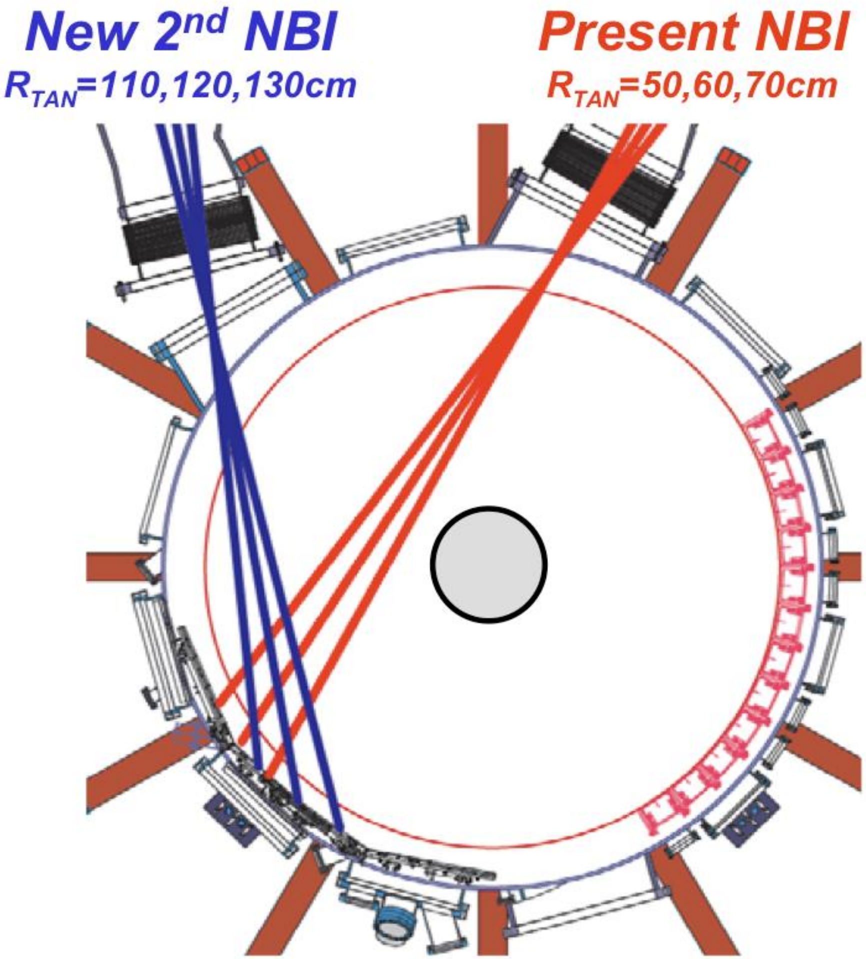
- most sensitive to passing particles

$$S = \iint W F_f \, dE dP$$

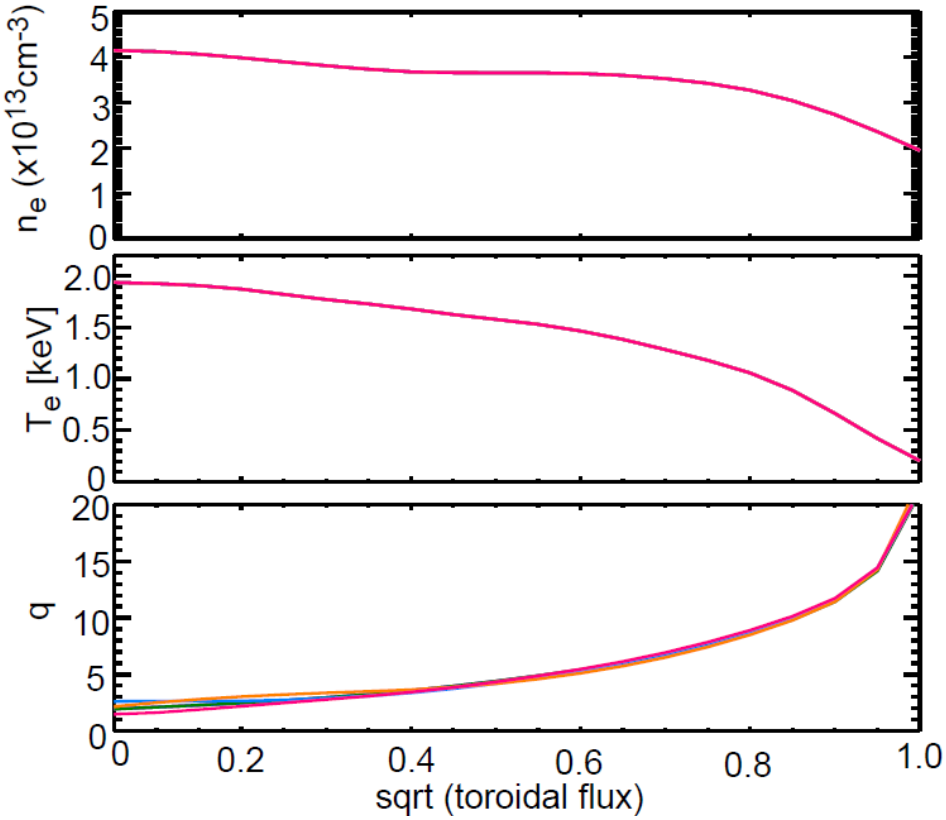


A. Bortolon, Rev. Sci. Instrum 2010

Fast Ion Distribution from NBI Line #1 and #2 is Simulated with TRANSP



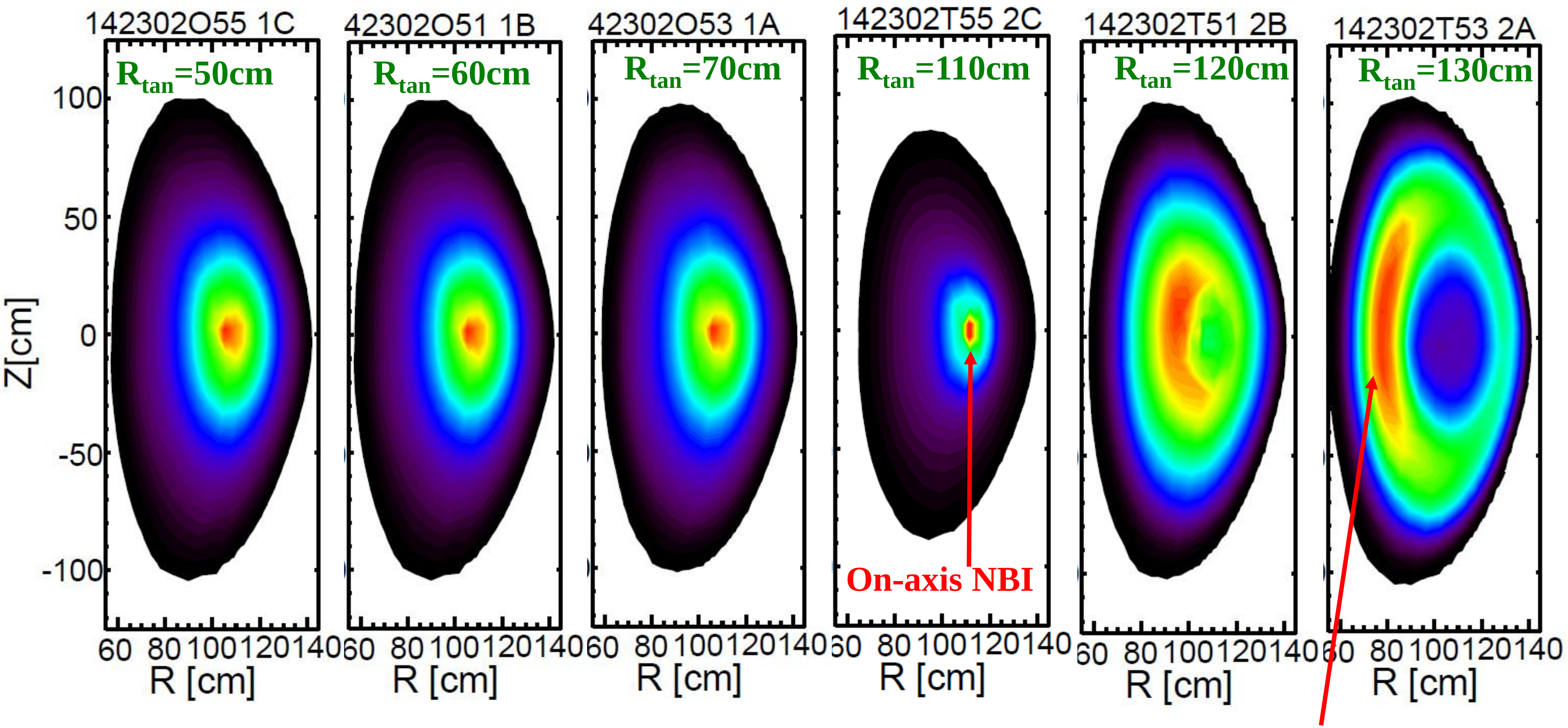
Input plasma profiles for TRANSP simulation



1C (R_{tan}=50cm), 1B (R_{tan}=60cm), 1A (R_{tan}=70cm)
2C (R_{tan}=110cm), 2B (R_{tan}=120cm), 2A (R_{tan}=130cm)

Fast Ion Density Profile Varies with Neutral Beam Source

More perpendicular → More Tangential



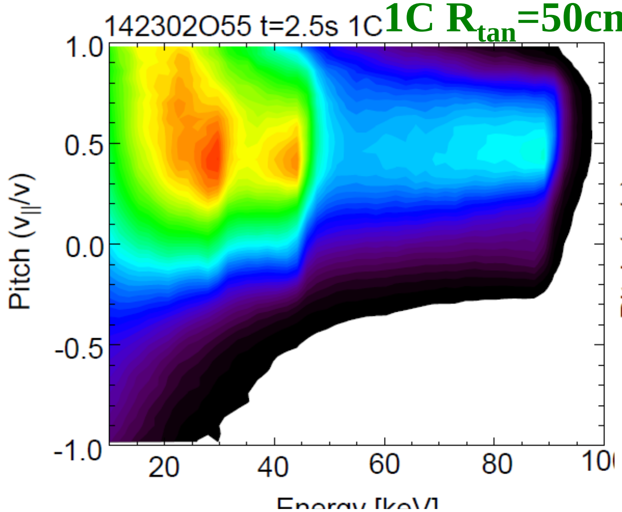
On-axis NBI

Passing fast ions spend more time at
high field side due to small major radius

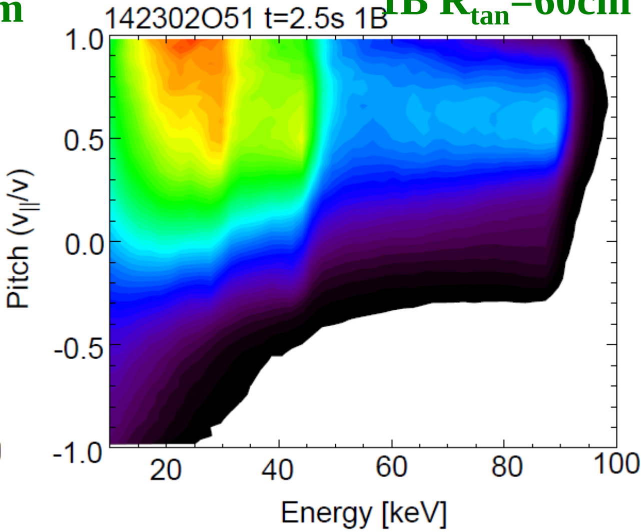
Fast Ion Pitch Angle Varies with Neutral Beam Source

NB Line #1 (more perpendicular)

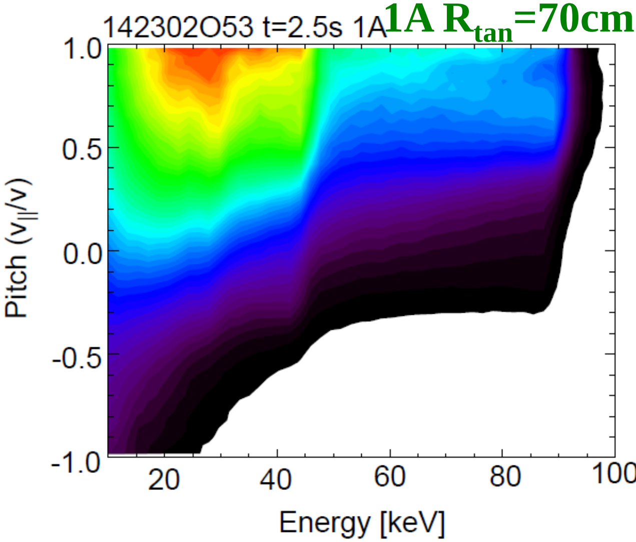
1C R_{tan}=50cm



1B R_{tan}=60cm

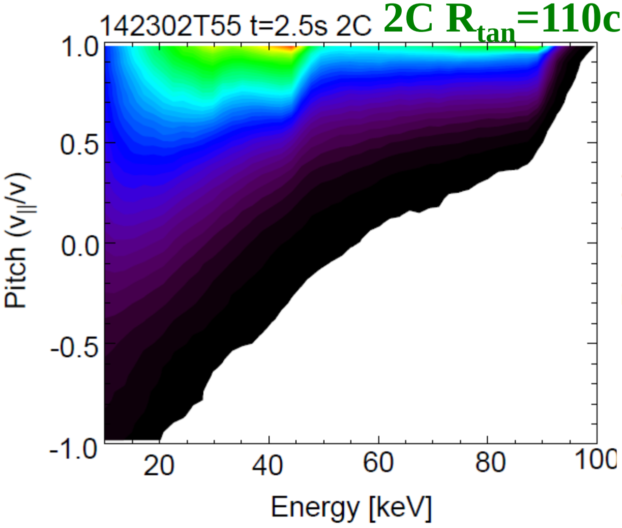


1A R_{tan}=70cm

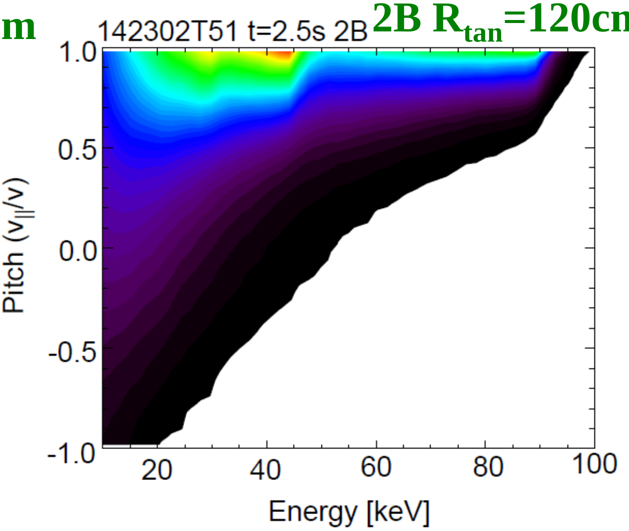


NB Line #2 (more tangential)

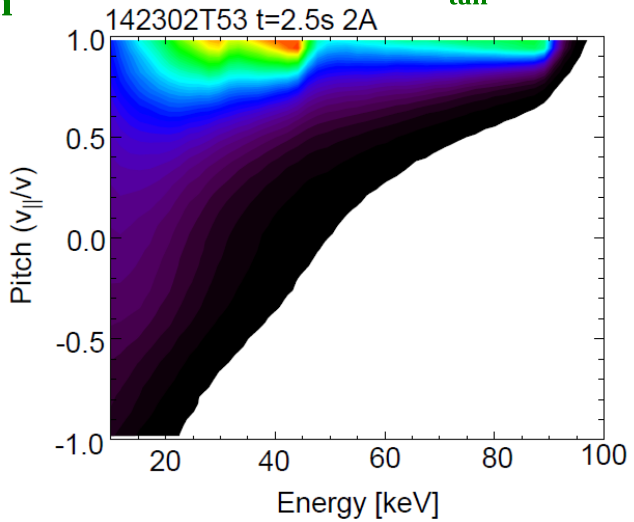
2C R_{tan}=110cm



2B R_{tan}=120cm



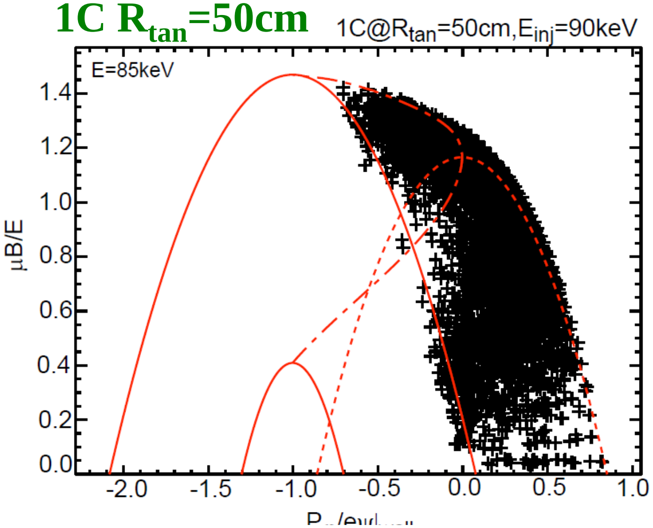
2A R_{tan}=130cm



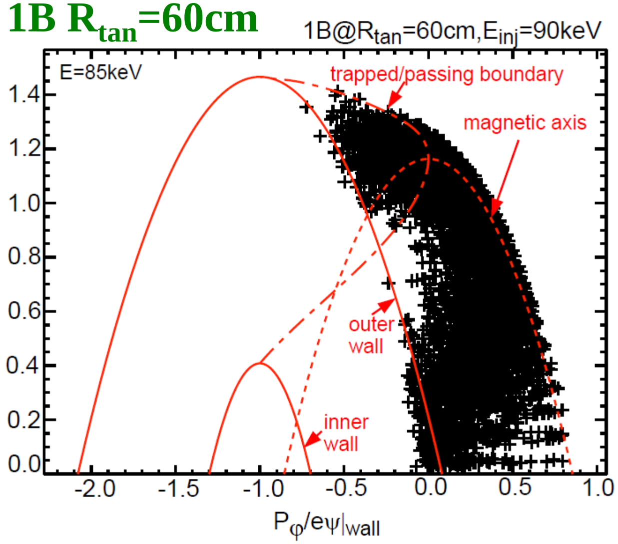
Fast Ion Distribution in Constants-of-motion Space Varies with Neutral Beam Source

NB Line #1 (more perpendicular)

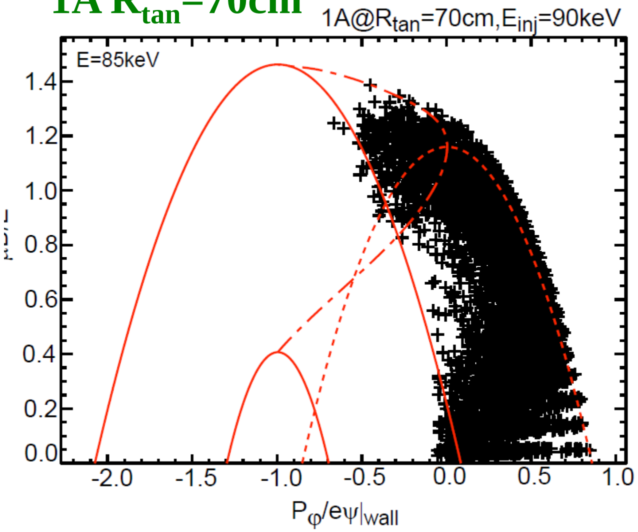
1C R_{tan}=50cm



1B R_{tan}=60cm

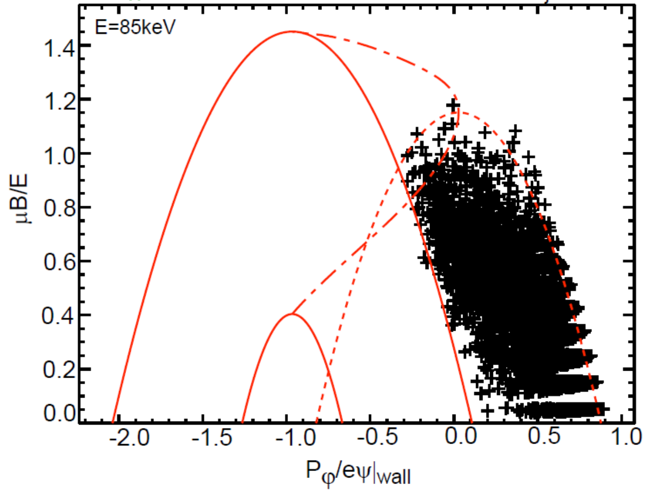


1A R_{tan}=70cm

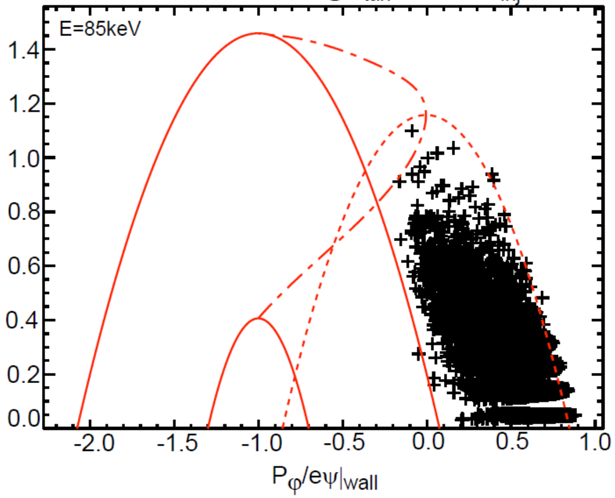


NB Line #2 (more tangential)

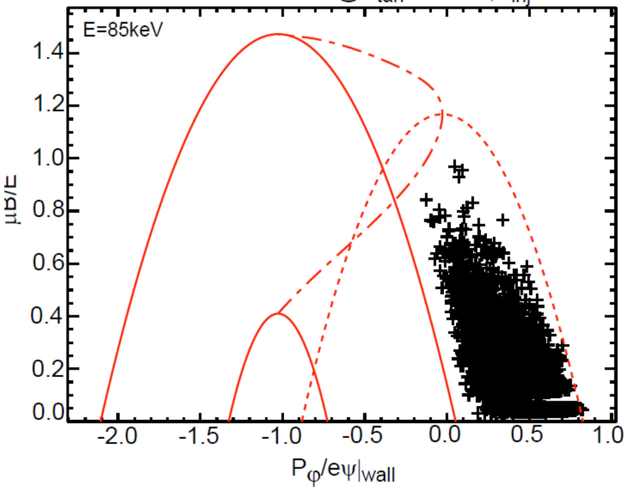
2C R_{tan}=110cm



2B R_{tan}=120cm

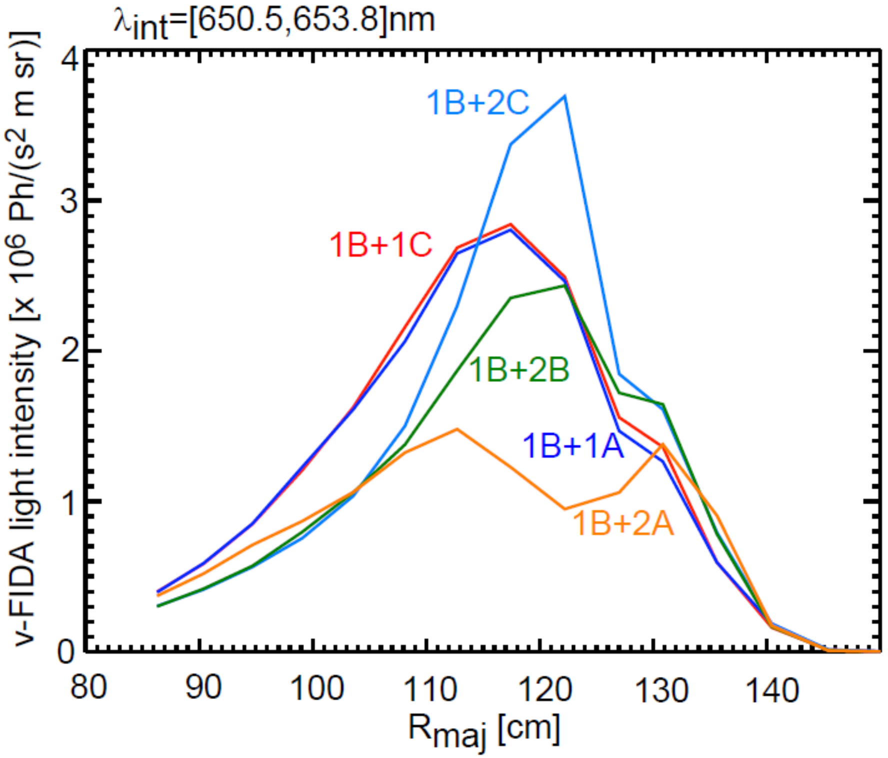


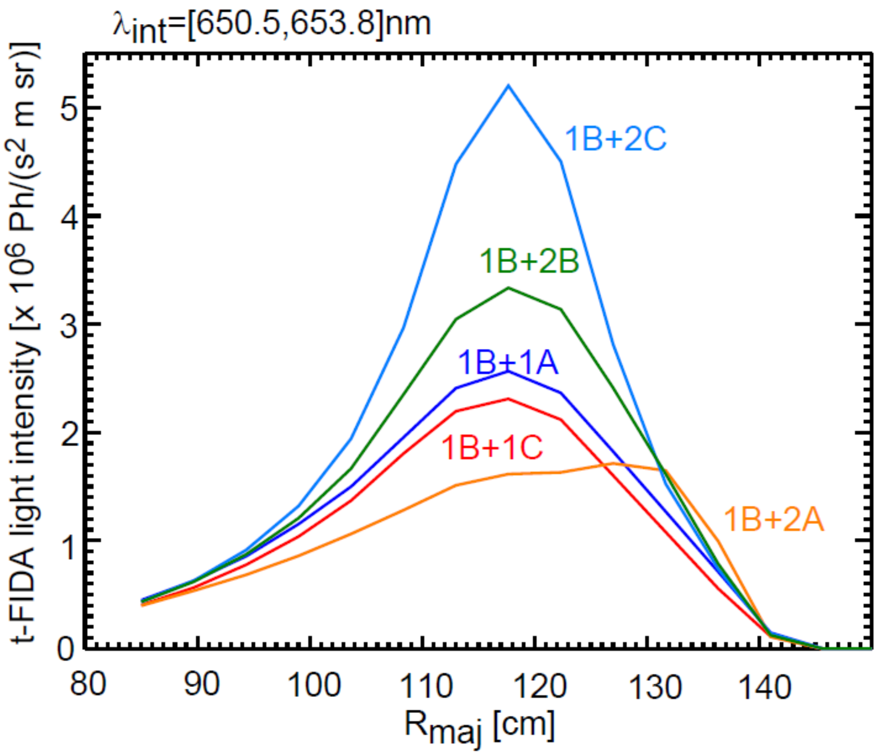
2A R_{tan}=130cm



FIDA Spatial Profile/Magnitude is Expected to Vary with Different Neutral Beam Source

v-FIDA (most sensitive to trapped particles) **t-FIDA (most sensitive to passing particles)**





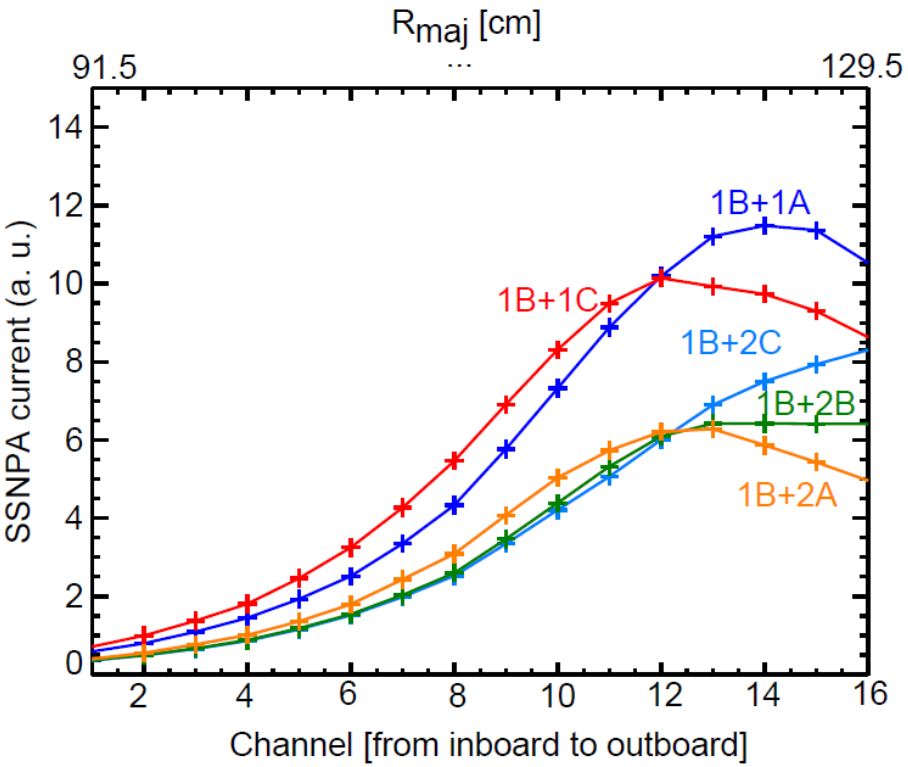
When switching from the existing NBI line to new NBI line,

- Significant magnitude difference is expected for both v-FIDA and t-FIDA systems.
- Significant profile difference is expected for v-FIDA

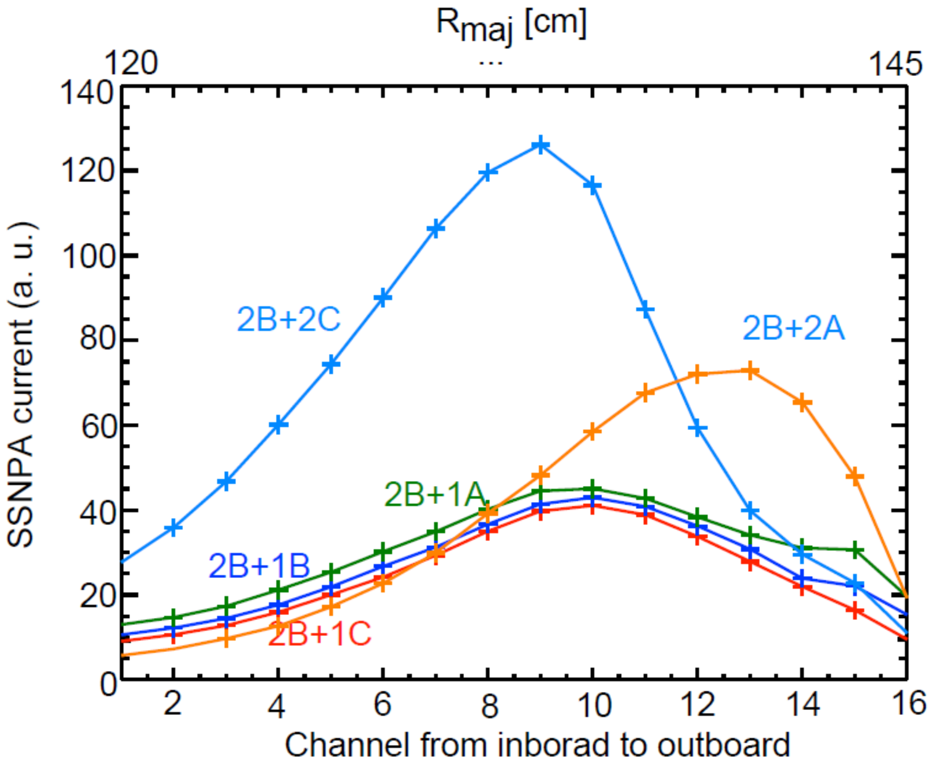
Note: NB source 1B provides beam neutrals for FIDA systems.

SSNPA Profile is Expected to be Different When Switching from Neutral Beam Line #1 to #2

r-SSNPA (mostly sensitive to trapped particles)



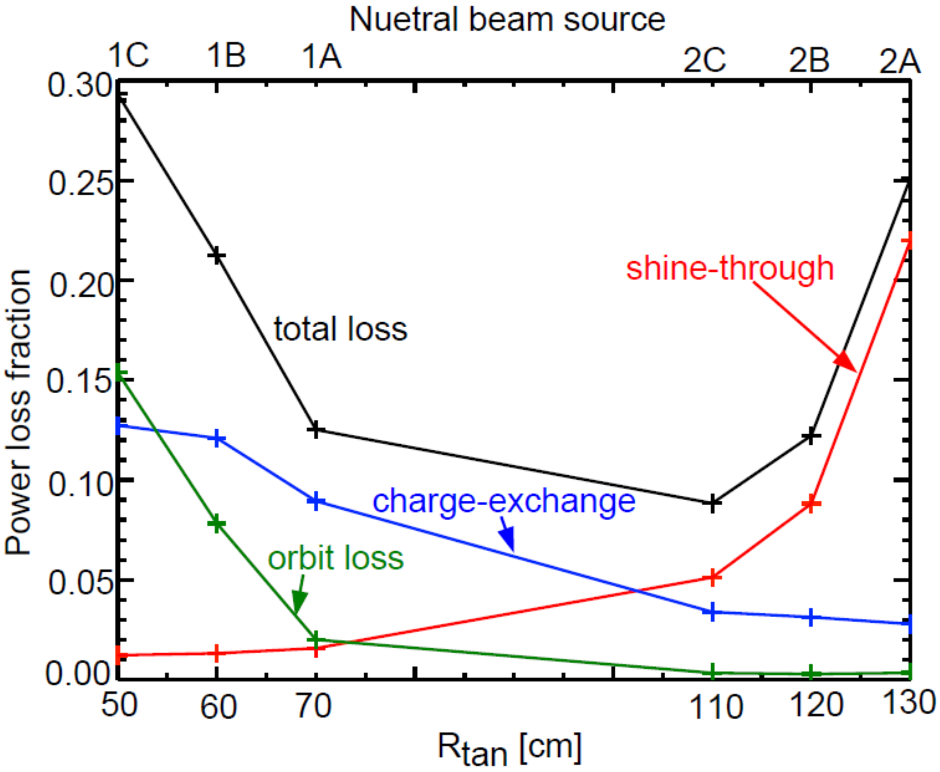
t-SSNPA (mostly sensitive to passing particles)



When switching from the existing NBI line to new NBI line,

- Significant magnitude difference is expected for both r-SSNPA and t-SSNPA systems.
- Significant profile difference is expected for t-SSNPA

Shine-through Loss Dominates for the New NBI



Existing NBI (R_{tan}=50,60,70cm)

1C: mainly prompt loss

1B and 1A: charge-exchange loss

New NBI (R_{tan}=110,120,130cm)

2C/2B/2A: shine-through loss

Plan of Beam Ion Confinement Experiment

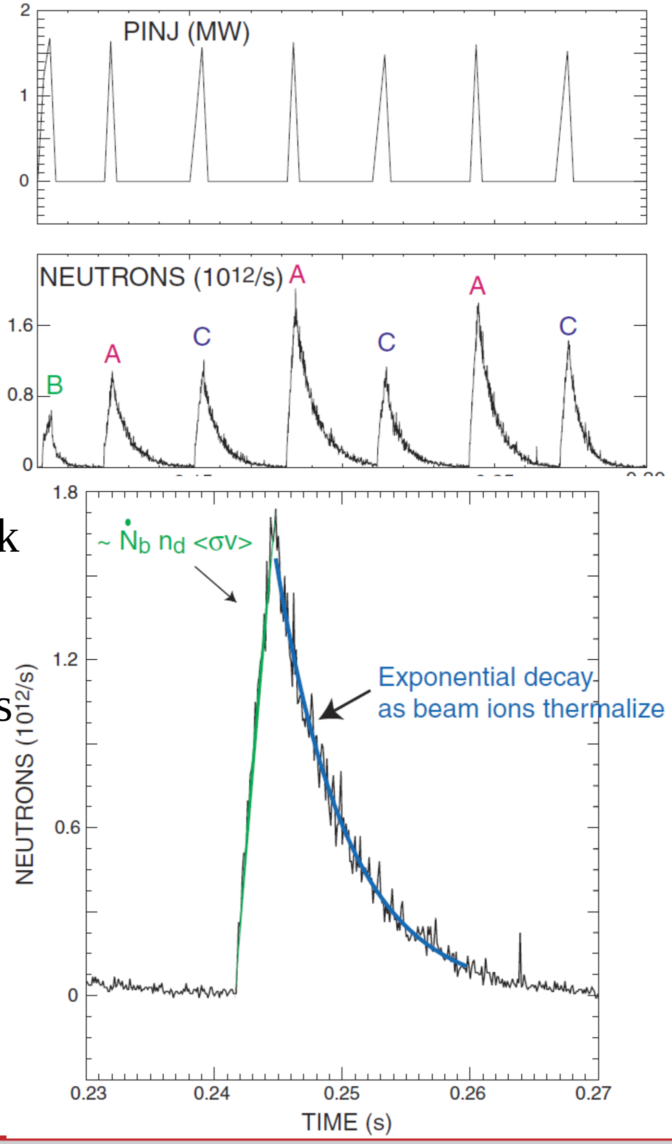
Objective

- Characterize beam ion confinement from NBI line #1 & #2
- Investigate the dependence of beam ion confinement on beam source, injection energy and plasma current.
- Compare with the classical theory (NUBEAM, FIDAsim)

Approach

- Inject short ($\sim$20ms<$t_{slowingdown}$) neutral beam pulses to check neutron build-up and decay rate.
- Inject relatively long ($\sim$90ms>$t_{slowingdow}$) neutral beam pulses to get stationary beam ion slowing-down distribution.
- E_{inj}=65keV vs. 90keV for all six neutral beam sources; I_p=0.7MA vs. 0.55MA at B_t=0.65T
- Monitor fast ion losses with sFLIP in all scenarios.

W. W. Heidbrink, Nucl. Fusion 2003



Summary

- It is important to check beam ion confinement on NSTX-U and gain confidence in utilizing the 2nd NBI as a tool to drive current, control q or pressure profile.

- A comprehensive set of fast ion diagnostics will be used to study the fast ion confinement. Diagnostics are nearly ready for experiments.

- Modelling with TRANSP and FIDAsim suggests that FIDA and SSNPA profile or signal magnitude will change with neutral beam source.

- Experimental plan and data analysis tools for beam ion confinement on NSTX-U have been developed.